RESIDENTIAL ACM APPENDIX RC

Appendix RCF – Procedures for Field Verification and Diagnostic Testing ~~Standard Procedure for Determining the Seasonal Energy Efficiencies~~ of Air Distribution Systems

RCF1 ~~Introduction~~Purpose and Scope

ACM RC-2005 contains procedures for measuring the air leakage in forced air distribution systems as well as procedures for verifying duct location, surface area and R-value.

ACM RC-2005 applies to air distribution systems in both new and existing low-rise residential buildings.

ACM RC-2005 provides required procedures for installers, HERS raters and others who need to perform field verification and diagnostic testing to verify the efficiency of air distribution systems. Algorithms for determining distribution system efficiency are contained in Chapter 4 of the residential ACM. Table RC-1 is a summary of the tests and criteria included in ACM RC-2005.

Table RC-1 – Summary of Diagnostic Measurements

Diagnostic	Description	Procedure
Supply Duct Location, Surface Area and R-factor	Verify that duct system was installed according to the design, including location, size and length of ducts, duct insulation R-value and installation of buried ducts.	RC4.1~~RF4.3~~ Diagnostic Supply Duct Location, Surface Area and R-value
Duct Leakage	Verify that duct leakage is less than the criteria or in the case of existing ducts that all accessible leaks have been sealed	RC4.3 Diagnostic Duct Leakage

~~This appendix describes the measurement and calculation methods for determining air distribution system efficiency.~~

RCF2 Instrumentation Specifications

The instrumentation for the air distribution diagnostic measurements shall conform to the following specifications:

RCF2.1 Pressure Measurements

All pressure measurements shall be measured with measurement systems (i.e. sensor plus data acquisition system) having an accuracy of ± 0.2 Pa. All pressure measurements within the duct system shall be made with static pressure probes as specified by the measurement equipment manufacturer.

~~RF4.1.2 Fan Flow Measurements~~

~~All measurements of distribution fan flows shall be made with measurement systems (i.e. sensor plus data acquisition system) having an accuracy of ±5% reading or ±5 cfm whichever is greater.~~

RCF2.23 Duct Leakage Measurements

The measurement of air flows during duct leakage -testing shall have an accuracy of ±3% of measured flow using digital gauges.

RC2.3 Calibration

All instrumentation used for ~~fan flow and~~ duct leakage diagnostic measurements shall be calibrated according to the manufacturer's calibration procedure to conform to the above accuracy requirement. All testers performing diagnostic tests shall obtain evidence from the manufacturer that the equipment meets the accuracy specifications. The evidence shall include equipment model, serial number, the name and signature of the person of the test laboratory verifying the accuracy, and the instrument accuracy. All diagnostic testing equipment is subject to re-calibration when the period of the manufacturer's guaranteed accuracy expires.

RCF3 Apparatus

RC3.1 Duct Pressurization

~~4.2.1 System Fan Flows~~

~~HVAC system fan flow shall be measured using one of the following methods.~~

~~4.2.1.1 Plenum pressure matching measurement~~

~~The apparatus for measuring the system fan flow shall consist of a duct pressurization and flow measurement device (subsequently referred to as a fan flowmeter [see section 4.3.7.2.2.]) meeting the specifications in 4.1.3, a static pressure transducer meeting the specifications in Section 4.1.1, and an air barrier between the return duct system and the air handler inlet. The measuring device shall be attached at the air handler blower compartment door. All registers shall be in their normal operating condition. The static pressure probe shall be fixed to the supply plenum so that it is not moved during this test.~~

~~4.2.1.2 Flow hood measurement~~

~~A flow hood meeting the specifications in section 4.1.2. can be used to verify the fan flow at the return register(s) after the completion of a rough-in duct leakage measurement. All registers shall be in their normal operating position. Measurement(s) shall be taken at the return grill(s).~~

~~4.2.2 Duct Leakage~~

The apparatus for fan pressurization duct leakage measurements shall consist of a duct pressurization and flow measurement device meeting the specifications in Section RC24.1.3.

RC3.2 Duct Leakage to Outside (Existing Duct Systems)

The apparatus for measuring duct leakage to outside shall include a fan that is capable of maintaining the pressure within the conditioned spaces in the house 25 Pa relative to the outdoors. The fan most commonly used for this purpose is known as a "blower door", and is typically installed within a temporary seal of an open doorway.

RC3.3 Smoke-Test of Accessible-Duct Sealing (Existing Duct Systems)

The apparatus for determining and verifying sealing of all accessible ducts shall also include means for introducing controllable amounts of non-toxic visual smoke into the duct pressurization apparatus for identifying leaks in accessible portions of the duct system. Adequate smoke shall be used to assure that any accessible leaks will emit visibly identifiable smoke.

RCF4 Procedures

The following sections identify input values for building and HVAC system (including ducts) using either default or diagnostic information.

RF4.3.1 Building Information

The calculation procedure for determining air distribution efficiencies requires the following building information:

1. Climate zone for the building,
2. Conditioned floor area,
3. Number of stories,
4. Supply duct location and
5. Floor type.

4.3.1.1 Default Input

Using default values rather than diagnostic procedures produce relatively low air distribution system efficiencies.Default values shall be obtained from following sections:

1. The location of the duct system in Section 4.3.4,
2. The surface area and insulation level of the ducts in Sections 4.3.3, 4.3.4 and 4.3.6,
3. The system fan flow in Section 4.3.7, and
4. The leakage of the duct system in Section 4.3.8.

RF4.3.2 Diagnostic Input

Diagnostic inputs are used for the calculation of improved duct efficiency. This section describes procedures that may be used to verify diagnostic inputs for the calculation of improved duct efficiency.

- measure supply duct surface area as described in Section 4.3.3.2.?
- measure total duct system leakage as described in Section 4.3.8.
- measure system fan flow or observe the presence of a thermostatic expansion valve for claiming ACCA manual D design credit as described in Section 4.3.7.
- Observe the insulation level for the supply (R_s) and return (R_r) ducts outside the conditioned space as described in Section 4.3.6.
- Observe the presence of radiant barriers.

RF4.3 Supply Duct Surface Area

The supply-side and return-side duct surface areas shall be calculated separately. If the supply or return duct is located in more than one zone, the area of that duct in each zone shall be calculated separately. The duct surface area shall be determined using the following methods.

RF 4.3.3.1 Default Duct Surface Area

4.3.3.1.1 Duct Surface Area for More than 12 feet of Duct Outside Conditioned Space

The default duct surface area for supply and return shall be calculated as follows:

For supplies:

$$A_{S,}\text{total} = 0.27 \times A_{floor}$$ Equation RF1

For returns:

Equation RF2

Where K_t (return duct surface area coefficient) shall be 0.05 for one story building and 0.1 for two or more stories.

4.3.3.1.1 Duct Surface Area for Less Than 12 feet of Duct Outside Conditioned Space

For HVAC systems with air handlers located outside the conditioned space but with less than 12 feet of duct located outside the conditioned space including air handler and plenum, the duct surface area outside the conditioned space shall be calculated as follows:

$$A_{s,out} - 0.027\ A_{floor}$$ Equation RF3

Where $A_{s,out}$ is substituted for $A_{s,attic}$; $A_{s,crawl}$; or $A_{s,base}$ depending on the location of the ducts.

RF4.3.3.2 Diagnostic Duct Surface Area

A well-designed duct system can reduce the length of the supply duct. Smaller duct surface area will result in reduced duct conduction losses. Duct surface area shall be calculated from measured duct lengths and nominal outside diameters (for round ducts) or outside perimeters (for rectangular ducts) of each duct run in the building. Improved conduction losses can be claimed for reduced supply duct surface area only (it does not apply to the return duct). Supply plenum surface area shall be included in the supply duct surface area. Diagnostic duct surface area requires measuring duct surface areas separately for each location outside conditioned space ($A_{s,attic}$; $A_{s,crawl}$; or $A_{s,base}$

RF4.4 Duct Location

Duct location determines the external temperature for duct conduction losses, the temperature for return leaks, and the thermal regain of duct losses. Default duct surface areas by locations of the supply duct shall be obtained from Table 4.1. The default duct surface area for crawlspace and basement applies only to buildings with all supply ducts installed in the crawlspace or basement. If the supply duct is installed in locations other than crawlspace or basement, the default supply duct location shall be "Other".

If ducts are installed in multiple locations, air distribution efficiency shall be calculated for each duct location. Total air distribution efficiency for the house shall be the weighted average based on the floor area served by each duct system.

	Supply Duct Surface Area		**Return Duct Surface Area**	
Supply or Return Duct Location	One story	Two or more story	One story	Two or more story
Attic	100% attic	65% attic 35% conditioned space	100% attic	100% attic
Crawlspace	100% crawlspace	65% crawlspace 35% conditioned space	100% attic	100% attic
Basement	100% Basement	65% basement 35% conditioned space	100% Basement	100% Basement
Other	100% attic	65% attic 35% conditioned space	100% attic	100% attic

~~4.3.5 Climate and Duct Ambient Conditions for Ducts Outside Conditioned Space~~

~~Duct ambient temperature for both heating and cooling at different duct locations shall be obtained from Table RF2. Indoor dry-bulb (T_{in}) temperature for cooling is 78°F. The indoor dry-bulb temperature for heating is 70°F. Reduction of attic temperature and the reduction in solar radiation effect due to radiant barriers shall only be applied to cooling calculations. The procedures for the installation of radiant barriers shall be as described in ACM Section 4.23. Attic temperatures for houses with radiant barriers shall be obtained from Table RF2.~~

~~Table RF2 – Default Assumptions for Duct Ambient Temperature~~

	~~Duct Ambient Temperature for Heating, $T_{heat,amb}$~~			~~Duct Ambient Temperature for Cooling, $T_{cool,amb}$~~				
~~Climate zone~~	~~Attic~~	~~Crawlspace~~	~~Basement~~	~~Attic~~	~~Attic w/ radiant barrier (supply)~~	~~Attic w/ radiant barrier (return)~~	~~Crawlspace~~	~~Basement~~
~~1~~	~~52.0~~	~~52.2~~	~~48.9~~	~~60.0~~	~~65.4~~	~~61.2~~	~~54.0~~	~~49.1~~
~~2~~	~~48.0~~	~~48.7~~	~~56.5~~	~~87.0~~	~~84.3~~	~~84.2~~	~~78.0~~	~~64.5~~
~~3~~	~~55.0~~	~~54.9~~	~~58.3~~	~~80.0~~	~~79.4~~	~~78.2~~	~~71.8~~	~~62.8~~
~~4~~	~~53.0~~	~~53.1~~	~~56.6~~	~~79.0~~	~~78.7~~	~~77.4~~	~~70.9~~	~~61.4~~
~~5~~	~~49.0~~	~~49.6~~	~~52.3~~	~~74.0~~	~~75.2~~	~~73.1~~	~~66.4~~	~~56.8~~
~~6~~	~~57.0~~	~~56.7~~	~~59.9~~	~~81.0~~	~~80.1~~	~~79.1~~	~~72.7~~	~~64.1~~
~~7~~	~~62.0~~	~~61.1~~	~~60.4~~	~~74.0~~	~~75.2~~	~~73.1~~	~~66.4~~	~~61.6~~
~~8~~	~~58.0~~	~~57.6~~	~~60.1~~	~~80.0~~	~~79.4~~	~~78.2~~	~~71.8~~	~~63.9~~
~~9~~	~~53.0~~	~~53.1~~	~~59.6~~	~~87.0~~	~~84.3~~	~~84.2~~	~~78.0~~	~~66.4~~
~~10~~	~~53.0~~	~~53.1~~	~~61.1~~	~~91.0~~	~~87.1~~	~~87.6~~	~~81.6~~	~~68.9~~
~~11~~	~~48.0~~	~~48.7~~	~~59.5~~	~~95.0~~	~~89.9~~	~~91.0~~	~~85.1~~	~~69.5~~
~~12~~	~~50.0~~	~~50.4~~	~~59.3~~	~~91.0~~	~~87.1~~	~~87.6~~	~~81.6~~	~~67.8~~
~~13~~	~~48.0~~	~~48.7~~	~~58.4~~	~~92.0~~	~~87.8~~	~~88.4~~	~~82.4~~	~~67.6~~
~~14~~	~~39.0~~	~~40.7~~	~~55.4~~	~~99.0~~	~~92.7~~	~~94.4~~	~~88.7~~	~~68.6~~
~~15~~	~~50.0~~	~~50.4~~	~~63.4~~	~~102.~~	~~94.8~~	~~96.9~~	~~91.3~~	~~74.6~~
~~16~~	~~32.0~~	~~34.4~~	~~43.9~~	~~80.0~~	~~79.4~~	~~78.2~~	~~71.8~~	~~54.1~~

RC4.6 1 Diagnostic Supply Duct Location, Surface Area and R-value~~Duct Wall Thermal Resistance~~

The performance calculations in ACM R4 allow credit for duct systems that are designed to be in advantageous locations, with reduced supply duct surface areas and/or higher than default R-values. Compliance credit may be taken for one or more of these duct system improvements in any combination. The procedure in this section is used to verify that the duct system is installed according to the design and meets the requirements for compliance credit.

RC4.1.1 Duct System Design Requirements

The design shall show the location of equipment and all supply and return registers. The size, R-value, and location of each duct segment shall be shown in the design drawing which shall be cross referenced to the Supply Duct System Details report in the CF1-R. For ducts buried in attic insulation, the portion in contact with the ceiling or deeply buried shall be shown and the design shall include provisions for ducts crossing each other, interacting with the structure, and changing vertical location to connect with elevated equipment or registers as

required. Credit shall be allowed for buried ducts only in areas where the ceiling is level and there is at least 6 inches of space between the outer jacket of the installed duct and the roof sheathing above.

RC4.1.2 Verifying the Duct System Installation

The location of all supply and return registers shall be verified from an inspection of the interior of the dwelling unit. The location of the equipment and the size, R-value and location of each duct segment shall be verified by observation in the spaces where they are located. Deviations from the design shall not be allowed.

RC4.1.3 Verification for Ducts Buried in Attic Insulation

The procedure of RC4.2.2 shall be carried out prior covering the ducts with insulation. Ducts to be buried shall be insulated to R4.2 or greater. In addition ducts designed to be in contact with the ceiling shall be in continuous contact with the ceiling drywall or ceiling structure not more that 3.5 inches from the ceiling drywall. A sign must be hung near the attic access reading "Caution: Buried Ducts. Markers indicate location of buried ducts." All ducts which will be completely buried shall have vertical markers which will be visible after insulation installation at not more than every 8 feet of duct length and at the beginning and end of each duct run.

After the ceiling insulation is installed, the R-value and type of insulation listed on the Duct System Details shall be verified. Ceiling insulation shall be level and uniform, mounding at ducts is not allowed.

RC4.2 System Fan Flow

For the purpose of establishing duct leakage criteria, the total fan flow shall be calculated using RC4.2.1, RC4.2.2 or RC4.2.3.

RC4.2.1 Default System Fan Flow

Default system fan flow may be used only for homes where the duct system is being tested before the air conditioning and heating system is installed and the equipment specification is not known. For heating only systems the default fan flow shall be 0.5 CFM/CFA. For systems with cooling, the default fan flow shall be 400 CFM per ton of rated cooling capacity calculated by the ACM using the procedure in ACM REF-2005 or the heating only value whichever is greater.

RC4.2.2 Nominal System Fan Flow

For heating only systems the fan flow shall be 21.7 x Heating Capacity in thousands of Btu/hr. For systems with cooling, the fan flow shall be 400 CFM per nominal ton of rated cooling capacity at ARI conditions or the heating only value whichever is greater.

RC4.2.3 Measured System Fan Flow

The fan flow shall be shall be as measured according to the procedure in ACM REF-2005.

~~***4.3.1 Default Duct Insulation R-value***~~

~~Default duct wall thermal resistance is R4.2. An air film resistance of 0.7 [h ft^2-^{o}F/BTU] shall be added to the duct insulation R-value to account for external and internal film resistance.~~

~~***4.3.2 Diagnostic Duct Wall Thermal Resistance***~~

~~Duct wall thermal resistance shall be determined from the manufacturer's specification observed during diagnostic inspection. If ducts with multiple R0values are installed, the lowest duct R-value shall be used. If a duct with a higher R value than 4.2 is installed, the R-value shall be clearly stated on the building plan and a visual inspection of the ducts must be performed to verify the insulation values. In case the space on top of the duct boot is limited and cannot be inspected, the insulation R-value within two feet of the boot to which the duct is connected may be excluded from the determination of the overall system R-value.~~

4.3.7 System Fan Flow

4.3.7.1 Default Fan Flow

The default cooling fan flow with an air conditioner and for heating with a heat pump for climate zones 8 through 15 shall be calculated as follows:

Qe = 0.70 Afloor (4.4) 4.7

The default cooling fan flow with an air conditioner and for heating with a heat pump for **climate zones 1 through 7 and 16** and heating fan flow for forced air furnaces for all climate zones shall be calculated as follows:

$$Q_e = 0.50\ A_{floor} \qquad \text{Equation RF4}$$

4.3.7.2 Diagnostic Fan Flow

To obtain duct efficiency credit for duct systems designed according to ACCA Manual D, a diagnostic fan flow measurement must be performed or the installation of a thermostatic expansion valve must be verified. The access panel on the cooling coil shall be removable for the verification of a thermostatic expansion valve. For ACCA Manual D designed duct system, engineering calculations and the building plan for duct sizing and layout shall also be prepared. The diagnostic fan flow measurement shall be measured using one of the following methods:

4.3.7.2.1 Diagnostic Fan Flow Using Flow Hood:

To measure the system return fan flow, all registers shall be fully open, and the air filter shall be installed. Turn on the system fan and measure the fan flow at the return grille(s) with a calibrated flow hood to determine the total system return fan flow. The system fan flow (Q_e) shall be the sum of the measured return flows.

4.3.7.2.2 Diagnostic Fan Flow Using Plenum Pressure Matching:

The fan flow measurement shall be performed using the following procedures:

1. With the system fan on (in heating mode with burners on for heating, or in cooling mode with compressor on), measure the pressure difference (in pascal) between the supply plenum and the conditioned space (ΔP_{sp}). P_{sp} is the target pressure to be maintained during the fan flow tests. If there is no access to the supply plenum, then place the pressure probe in the nearest supply duct. Adjust the probe to achieve the highest pressure and then firmly attach the probe (e.g., with duct tape) to ensure that it does not move during the fan flow test.
2. Block the return duct from the plenum upstream of the air handler fan and the fan flowmeter. Filters are often located in an ideal location for this blockage.
3. Attach the fan flowmeter device to the duct system at the air handler. For many air handlers, there will be a removable section that allows access to the fan that is suitable for this purpose. Assure that there is no significant leakage between the fan flowmeter and the system fan.
4. If the fan flowmeter is connected to the air handler outside the conditioned space, then the door or access panel between the conditioned space and the air handler location shall be opened.
5. Turn on the system fan and the fan flowmeter, adjust the fan flowmeter until the pressure between supply plenum and conditioned space matches P_{sp}.
6. Record the flow through the flowmeter (Q_e, cfm) - this is the diagnostic fan flow.

In some systems, typical system fan and fan flowmeter combinations may not be able to produce enough flow to reach P_{sp}. In this case record the maximum flow (Q_{max}, cfm) and pressure (P_{max}) between the supply plenum and the conditioned space. The following equation shall be used to correct measured system flow and pressure (Q_{max} and P_{max}) to operating condition (Q_e) at operating pressure (P_{sp}).

$$Q_e = Q_{max}\left(\frac{P_{sp}}{P_{max}}\right)^{\frac{1}{2}} \qquad (4.6)$$

4.3.8 Duct Leakage

4.3.8.1 Duct Leakage Factor for Delivery Effectiveness Calculations

Default duct leakage factors shall be obtained from Table RF3, using the "not Tested" values.

Duct leakage factors shown in Table RF3 shall be used in calculations of delivery effectiveness.

Table RF3 – Duct Leakage Factors

	Duct Leakage Diagnostic Test Performed using Section 4.3.8.2 Procedures	**$a_s = a_r =$**
Duct systems in homes built prior to 1999	Not tested	0.86
Duct systems in homes built after 1999	Not tested	0.89
Duct systems in homes of all ages, – System with refrigerant based cooling, tested after house and HVAC system completion	(Q_{25}) Total leakage is less than 0.06 Q_{acool}	0.96
Duct systems in homes of all ages, – System without refrigerant based cooling, tested after house and HVAC system completion	(Q_{25}) Total leakage is less than 0.06 Q_{aheat}	0.96
Duct systems with refrigerant based cooling, in homes built after 1999, System tested with air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.06 Q_{acool} and final duct integrity verified	0.96
Duct systems without refrigerant based cooling, in homes built after 1999, System tested with air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.06 Q_{aheat} and final duct integrity verified	0.96
Duct systems with refrigerant based cooling, in homes built after 1999, System tested without air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.04 Q_{acool} and final duct integrity verified	0.96
Duct systems without refrigerant based cooling, in homes built after 1999, System tested without air handler installed, but prior to installation of the interior finishing wall	(Q_{25}) Total leakage is less than 0.04 Q_{aheat} and final duct integrity verified	0.96

RC4.8.23 Diagnostic Duct Leakage

Diagnostic duct leakage measurement is used by installers and raters to quantify verify that total leakage for the calculation of air distribution efficiency meets the criteria for any sealed duct system specified in the compliance documents. Diagnostic Duct Leakage from Fan Pressurization of Ducts (Section RC4.3.1) is the only procedure that may be used by a HERS rater to verify duct sealing in a new home. To obtain the improved duct efficiency for sealing the duct system, a diagnostic leakage test as described in section 4.3.8.2.1 or 4.3.8.2.2 must be performed. Table RC-2 shows the leakage criteria and test procedures that may be used to demonstrate compliance. In addition to the minimum tests shown, existing duct systems may be tested to show they comply with the criteria for new duct systems. Houses built after 1/1/1999 shall not be allowed to claim duct leakage credit and diagnostic testing may not be done on any HVAC system that uses building cavities such as plenums or a platform return.

Table RC-2 Duct Leakage Tests

Case	User and Application	Leakage criteria, % of total fan flow	Procedure
Sealed and tested new duct systems	Installer Testing at Final HERS Rater Testing	6%	RC4.3.1
	Installer Testing at Rough- in, Air Handling Unit Installed	6% Installer Inspection at Final	RC4.3.2.1 RC4.3.2.3
	Installer Testing at Rough-in, Air Handling Unit Not Installed	4% Installer Inspection at Final	RC4.3.2.2 RC4.3.2.3
Sealed and tested altered existing duct system	Installer Testing HERS Rater Testing	15% Total Duct Leakage	RC4.3.1
	Installer Testing HERS Rater Testing	10% Leakage to Outside	RC4.3.3.
	Installer Testing and Inspection HERS Rater Testing and Verification	60% Reduction in Leakage and Inspection and Smoke Test	RC4.3.4 RC4.3.6 and RC4.3.7
	Installer Testing and Inspection HERS Rater Testing and Verification	Fails Leakage Test but All Accessible Ducts are Sealed Inspection and Smoke Test with 100% Verification	RC4.3.5 RC4.3.6 and RC4.3.7

RC4.38.12.1 Diagnostic Duct Leakage from Fan Pressurization of Ducts

The objective of this procedure is for an installer to determine or a rater to verify the total leakage of a new or altered duct system. The total duct leakage shall be determined by pressurizing both the supply and return ~~the~~ ducts to a pressure difference of 25 Pascals. The following procedure shall be used for the fan pressurization tests:

1. Verify that the air handler, supply and return plenums and all the connectors, transition pieces, duct boots and registers are installed. The entire duct system shall be included in the total leakage test.
2. For newly installed or altered ducts, verify that cloth backed rubber adhesive duct tape has not been used and if a platform or other building cavity used to house the air distribution system has been newly installed or altered, it contains a duct or is ducted with duct board or sheet metal.
3. Seal all the supply and return registers, except for one return register or the system fan access.
2. 4. Attach the fan flowmeter device to the duct system at the unsealed register or access door.
3. 5. Install a static pressure probe at a supply.
4. 6. Adjust the fan flowmeter to produce a 25 Pascal (0.1 in water) pressure difference between the supply duct and the outside or the building space with the entry door open to the outside.
5. 7. Record the flow through the flowmeter, ~~($Q_{total,25}$) -~~ this is the ~~total duct~~ leakage flow at 25 Pascals.
8. Divide the leakage flow by the total fan flow and convert to a percentage. If the leakage flow percentage is less than the criteria from Table RC~~F~~-2 the system passes.

When the diagnostic leakage test is performed and the measured total duct leakage is less than 6% of the total fan flow, the duct leakage factor shall be 0.96 as shown in Table R4-13~~RC3~~.

RC4.3.2~~8.2.2~~ Diagnostic Duct Leakage at Rough-in Construction Stage ~~Using An Aerosol Sealant Closure System~~

Installers may determine ~~D~~duct leakage in new construction ~~may be determined~~ by using diagnostic measurements at the rough-in building construction stage prior to installation of the interior finishing ~~wall when using an aerosol sealant closure system~~. When using this measurement technique, the installer shall complete additional ~~verification~~ inspection (as described in section RC4.~~3.8.2~~3.2.3) of duct integrity ~~shall be completed~~ after the finishing wall has been installed. In addition, after the finishing wall is installed, spaces between the register boots and the wallboard shall be sealed. Cloth backed rubber adhesive duct tapes shall not be used to seal the space between the register boot and the wall board.

The duct leakage measurement at rough-in construction stage shall be performed using a fan pressurization device. The duct leakage shall be determined by pressurizing both the supply and return ducts to 25 Pa. The following procedure (either RC4.3.2.1 or RC4.3.2.2) shall be used: ~~The procedures in Sections 4.3.8.2.2.1 and 4.3.8.2.2.2 shall be used for measuring duct leakage before the interior finishing wall is installed.~~

RC4.3.~~8.2.~~2.1 For Ducts with the Air Handling Unit Installed and Connected:

For total leakage:

1. Verify that supply and return plenums and all the connectors, transition pieces and duct boots have been installed. If a platform or other building cavity is used ~~as part of~~to house the air distribution system, it ~~must~~ shall contain a duct, and all return connectors and transition parts shall be installed and sealed. The platform, duct and connectors shall be included in the total leakage test. All joints shall be inspected to ensure that no cloth backed rubber adhesive duct tape is used.
2. Seal all the supply duct boots and return boxes except for one return duct box.
3. Attach the fan flowmeter device at the unsealed duct box.
4. Insert a static pressure probe at one of the sealed supply duct boots.
5. Adjust the fan flowmeter to maintain 25 Pa (0.1 in water) between the duct system and outside or the building space with the entry door open to the outside.
6. Record the flow through the flowmeter, this is the leakage flow at 25 Pascals.~~Record the air flow through the flowmeter ($Q_{total,25}$) - This is the total duct leakage at 25 Pa at rough-in stage.~~
7. Divide the leakage flow by the total fan flow and convert to a percentage. If the leakage flow percentage is less than the criteria from Table RC2 the system passes.~~Divide the measured total leakage by the total fan flow calculated from Equation RF4 or RF5~~.

~~If the total leakage is less than 6% of the total fan flow, the duct leakage factor shall be 0.96 as shown in Table RF3.~~

RC4.3~~8.2~~.2.2 For Ducts with Air Handling Unit Not Yet Installed:

For total leakage:

1. Verify that all the connectors, transition pieces and duct boots have been installed. If a platform or other building cavity is used ~~as part of~~to house the air distribution system, it must contain a duct, and all return connectors and transition parts shall be installed and sealed. The platform, duct and connectors shall be included in the total leakage test.
2. Use a duct connector to connect supply and/or return duct box to the fan flowmeter. Supply and return leaks may be tested separately. If there is only one return register, the supply and return leaks shall be tested at the same time.
3. Seal all the supply duct boots and/or return boxes except for one supply or return duct box.
4. Attach the fan flowmeter device at the unsealed duct box.
5. Insert a static pressure probe at one of the sealed supply duct boots.

6. Adjust the fan flowmeter to maintain 25 Pa (0.1 in water) between the building conditioned space and the duct system.

7. Record the flow through the flowmeter, this is the leakage flow at 25 Pascals.

~~Record the air flow through the flowmeter ($Q_{total,25}$) - This is the total duct leakage at 25 Pa.~~

8. ~~-~~Divide the leakage flow by the total fan flow and convert to a percentage. If the leakage flow percentage is less than the criteria from Table RC-2 the system passes.~~Divide the measured total leakage by the total fan flow calculated from Equation RF4 or RF5. If the total leakage is less than 4% of the total fan flow, the total duct leakage factor shall be 0.96 as shown in Table RF3 Table 4.3.~~

RC4.3~~8.2.2.3 Installer Visual Inspection at Final Construction Stage~~Post Rough-in Duct Leakage Verification~~

After installing the interior finishing wall and verifying that one of the above rough-in tests was completed, the following procedure shall be used: ~~one of the following post rough-in verification tests shall be performed to ensure that there is no major leakage in the duct system.~~

1. Remove at least one supply and one return register, and verify that the spaces between the register boot and the interior finishing wall are properly sealed.

2. If the house rough-in duct leakage test was conducted without an air handler installed, inspect the connection points between the air handler and the supply and return plenums to verify that the connection points are properly sealed.

3. Inspect all joints to ensure that no cloth backed rubber adhesive duct tape is used.

~~4.8.2.2.3.1 Visual Inspection~~

~~Remove at least one supply and one return register to verify that the spaces between the register boot and the interior finishing wall are properly sealed. In addition, if the house rough-in duct leakage test was conducted without an air handler installed, inspect the connection points between the air handler and the supply and return plenums to verify that the connection points are properly sealed. All joints shall be inspected to ensure that no cloth backed rubber adhesive duct tape is used.~~

~~*4.8.2.2.3.2 Pressure Pan Test*~~

~~With register dampers fully open, the house is pressurized to 25 pascals by a blower door, (if two registers are within 5 feet of each other and are connected to the same duct run, one register shall be sealed off before the pressure pan test is performed). The pressure difference across each register shall not exceed 1.5 Pa.~~

~~*4.8.2.2.3.3 House Pressure Test*~~

~~The pressure difference between the building conditioned space and a vented attic shall be measured to determine whether the house pressure is changed appreciably by the operation of the air handler. To perform this test, the pressure difference (P_{house} - P_{out}) between the building conditioned space and a vented attic (or outside if impossible to access the attic), shall be measured four times:~~

~~1. With the fan off (ΔP_{off1})~~

~~2. With the fan on (ΔP_{on})~~

~~3. With the fan on and the return grille 80% blocked (ΔP_{RB}). Block 80% on all return grilles if the house has two or more returns.~~

~~4. With the fan off (ΔP_{off2})~~

~~For each of these measurements, the five-second average pressure shall be measured 10 times and these 10 measurements shall be averaged.~~

~~For the house to pass this test, the following conditions must be true:~~

~~1. ΔP_{on} -(Δ P_{off2}+ΔP_{off1})/2 must be between +0.8 Pa and -0.8 Pa and~~

~~2. ΔP_{RB} -ΔP_{on} must be less than 0.8 Pa.~~

~~In addition, the absolute value of (Δ P_{off2} -ΔP_{off1}) must be less than 0.25 Pa, or else the test must be repeated. If the repeated test does not meet the above specified values, visual inspection or the pressure pan test or the fan pressurization test must be used. If these tests fail, the duct system needs to be properly sealed and re-verified by a fan pressurization test.~~

RC4.3.3 Duct Leakage to Outside from Fan Pressurization of Ducts

The objective of this test for altered existing duct systems only is to provide an alternate measurement of duct leakage to outdoors. The total duct leakage to outdoors shall be determined by pressurizing the ducts and the conditioned spaces of the house to 25 Pa. The following procedure shall be used for the fan pressurization test of leakage to outside:

1. Seal all the supply and return registers except one return register or the fan access door.
2. Attach the fan flowmeter device to the duct system at the unsealed register or access door.
3. Install a static pressure probe at the supply plenum.
4. Attach a blower door to an external doorway.
5. If any ducts are located in an unconditioned basement, all doors or accesses between the conditioned space and the basement shall be closed, and at least one operable door or window (if it exists) between the basement and outside shall be opened during the test.
6. If the ducts are located in a conditioned basement, any door between the basement and the remaining conditioned space shall be opened, and any basement doors or windows to outside must be closed during the test.
7. Adjust the blower door fan to provide 25 Pa [0.1 inches of water] pressure difference between the conditioned space and outside.
8. Adjust the fan/flowmeter to maintain zero pressure (±0.5Pa [±0.002 inches water]) between the ducts and the conditioned space, and adjust the blower door fan to maintain 25 Pa (±0.5Pa) [0.1 inch water (±0.002 inches water)] between the conditioned space and outside. This step may require several iterations.
9. Record the flow through the flowmeter (Q25 [Q0.1]); this is the duct leakage at 25 Pa [0.1 inch water].
10. Divide the leakage flow by the total fan flow and convert to a percentage. If the leakage flow percentage is less than the criteria from Table RC-2 the system passes.

RC4.3.4 Leakage Improvement from Fan Pressurization of Ducts

For altered existing duct systems which do not pass the Total Leakage (RC4.3.1) or Leakage to Outside (RC4.3.3) tests, the objective of this test is to show that the original leakage is reduced through duct sealing as specified in Table RC-2 The following procedure shall be used:.

1. Use the procedure in RC4.3.1 to measure the leakage before commencing duct sealing.
2. After sealing is complete use the same procedure to measure the leakage after duct sealing.
3. Subtract the sealed leakage from the original leakage and divide the remainder by the original leakage. If the leakage reduction is 60% or greater of the original leakage, the system passes.
4. Complete the Smoke Test specified in RC4.3.6
5. Complete the Visual Inspection specified in RC4.3.7.

RC4.3.5 Sealing of All Accessible Leaks

For altered existing duct systems that do not pass any of the Total Leakage (RC4.3.1), Leakage to Outside (RC4.3.3) or Leakage Improvement (RC4.3.4) tests, the objective of this test is to show that all accessible leaks are sealed and that excessively damaged ducts have been replaced. The following procedure shall be used:

1. Complete each of the leakage tests
2. Complete the Smoke Test as specified in RC4.3.6
3. Complete the Visual Inspection as specified in RC4.3.7.
4. Install required label on the system stating that the system fails the leakage tests.

RC4.3.6 Smoke-Test of Accessible Duct Sealing

For altered existing ducts that fail the leakage tests, the objective of the smoke test is to confirm that all accessible leaks have been sealed. The following procedure shall be used:

1. Inject either theatrical or other non-toxic smoke into a fan pressurization device that is maintaining a duct pressure difference of 25 Pa relative to the duct surroundings, with all grilles and registers in the duct system sealed.
2. Visually inspect all accessible portions of the duct system during smoke injection.
3. The system shall pass the test if either of the following conditions are met:
   i. No visible smoke exits the accessible portions of the duct system.; or
   ii. Smoke only emanates from the portion of the HVAC equipment containing the furnace vestibule which is gasketed and sealed by the manufacturer rather than from the ducts.

RC4.3.7 Visual Inspection of Accessible Duct Sealing

For altered existing ducts that fail the leakage tests, the objective of this inspection in conjunction with the smoke test (RC4.3.6) is to confirm that all accessible leaks have been sealed and that excessively damaged ducts have been replaced. The following procedure shall be used:

1. Visually inspect to verify that the following locations have been sealed:
   - Connections to plenums and other connections to the forced air unit
   - Refrigerant line and other penetrations into the forced air unit
   - Air handler door panel (do not use permanent sealing material, metal tape is acceptable)
   - Register boots sealed to surrounding material
   - Connections between lengths of duct, as well as connections to takeoffs, wyes, tees, and splitter boxes.
2. Visually inspect to verify that portions of the duct system that are excessively damaged have been replaced. Ducts that are considered to be excessively damaged are:
   - Flex ducts with the vapor barrier split or cracked with a total linear split or crack length greater than 12 inches
   - Crushed ducts where cross-sectional area is reduced by 30% or more
   - Metal ducts with rust or corrosion resulting in leaks greater than 2 inches in any dimension
   - Ducts that have been subject to animal infestation resulting in leaks greater than 2 inches in any dimension

~~4.4 Delivery Effectiveness (DE) Calculations~~

~~Seasonal delivery effectiveness shall be calculated using the seasonal design temperatures from Tables RF2.~~

4.4.1 Calculation of Duct Zone Temperatures

The temperatures of the duct zones outside the conditioned space are determined in Section 4.3.5 for seasonal conditions for both heating and cooling. If the ducts are not all in the same location, the duct ambient temperature for use in the delivery effectiveness and distribution system efficiency calculations shall be determined using an area weighted average of the duct zone temperatures:

$$T_{amb,s} = \frac{(A_{s,attic} + 0.001)T_{attic} + A_{s,crawl} \times T_{crawl} + A_{s,base} \times T_{base}}{A_{s,out} + 0.001} \quad \text{Equation RF5}$$

$$T_{amb,r} = \frac{A_{r,attic}\ T_{attic} + A_{r,crawl} \times T_{crawl} + A_{r,base} \times T_{base}}{A_{r,out}} \quad \text{Equation RF6}$$

The return ambient temperature, $T_{amb,r}$, shall be limited as follows:

For heating, the maximum $T_{amb,r}$ is $T_{in,heat}$. For cooling, the minimum $T_{amb,r}$ is $T_{in,cool}$.

4.4.2 Seasonal Delivery Effectiveness (DE)

The supply and return conduction fractions, B_s and B_r, shall be calculated as follows:

$$B_s = \exp\left(\frac{-A_{s,out}}{1.08Q_e \times R_s}\right) \quad \text{Equation RF7}$$

$$B_r = \exp\left(\frac{-A_{r,out}}{1.08Q_e \times R_r}\right) \quad \text{Equation RF8}$$

The temperature difference across the heat exchanger in the following equation is used:

for heating:

$$\Delta T_e = 55 \quad \text{Equation RF9}$$

for cooling:

$$\Delta T_e = -20 \quad \text{Equation RF10}$$

The temperature difference between the building conditioned space and the ambient temperature surrounding the supply, ΔT_s, and return, ΔT_r, shall be calculated using the indoor and the duct ambient temperatures.

$$\Delta T_s = T_{in} - T_{amb,s} \quad \text{Equation RF11}$$

$$\Delta T_r = T_{in} - T_{amb,r} \quad \text{Equation RF12}$$

The seasonal delivery effectiveness for heating or cooling systems shall be calculated using:

$$DE_{seasonal} = a_s B_s - a_s B_s (1 - B_r a_r)\frac{\Delta T_r}{\Delta T_e} - a_s (1 - B_s)\frac{\Delta T_s}{\Delta T_e} \quad \text{Equation RF13}$$

4.5 Seasonal Distribution System Efficiency

Seasonal distribution system efficiency shall be calculated using delivery effectiveness, equipment, load, and recovery factors calculated for seasonal conditions.

4.5.1 Equipment Efficiency Factor (F_{equip})

Equipment efficiency factor accounts for interactions between the duct system and the operation of the heating or cooling equipment. If the duct size and layout are designed and installed according to ACCA manual D and if the fan flow measurement meets the design specifications, the efficiency factor for F_{equip} is 1. Otherwise F_{equip} shall be 0.925. For heating, F_{equip} is 1.

4.5.2 Thermal Regain (F_{regain})

The reduction in building load due to regain of duct losses shall be calculated using the thermal regain factor. The default thermal regain factors are provided in Table RF4.

RFThermal Regain Factors

Supply Duct Location	Thermal Regain Factor [F_{regain}]
Attic	0.10
Crawlspace	0.12
Basement	0.30
Other	0.10

RF5 Definitions

aerosol sealant closure system*:* A method of sealing leaks by blowing aerosolized sealant particles into the duct system and which must include minute-by-minute documentation of the sealing process.

floor area :The floor area of enclosed conditioned space on all floors of a building, as measured at the floor level of the exterior surfaces enclosing the conditioned space.

delivery effectiveness :The ratio of the thermal energy delivered to the conditioned space and the thermal energy entering the distribution system at the equipment heat exchanger.

distribution system efficiency :The ratio of the thermal energy consumed by the equipment with the distribution system to the energy consumed if the distribution system had no losses or impact on the equipment or building loads.

equipment efficiency :The ratio between the thermal energy entering the distribution system at the equipment heat exchanger and the energy being consumed by the equipment.

equipment factor : F_{equip} is the ratio of the equipment efficiency including the effects of the distribution system to the equipment efficiency of the equipment in isolation.

fan flowmeter device*:* A device used to measure air flow rates under a range of test pressure differences.

flowhood**:** A device used to capture and measure the airflow at a register.

load factor : F_{load} is the ratio of the building energy load without including distribution effects to the load including distribution system effects.

pressure pan : a device used to seal individual forced air system registers and to measure the static pressure from the register.

radiant barrier : a surface of low emissivity (less than 0.05) placed inside an attic or roof space to reduce radiant heat transfer.

recovery factor : F_{recov} is the fraction of energy lost from the distribution system that enters the conditioned space.

thermal regain: The fraction of delivery system losses that are returned to the building.

~~RF6 Nomenclature~~

~~a_r = duct leakage factor (1-return leakage) for return ducts~~

~~a_s = duct leakage factor (1-supply leakage)p for supply ducts~~

~~A_{floor} = conditioned floor area of building, ft^2~~

~~$A_{r,out}$ = surface area of return duct outside conditioned space, ft^2~~

~~$A_{r,attic}$ = return duct area in attic, ft^2~~

~~$A_{r,base}$ = return duct area in basement, ft^2~~

~~$A_{r,crawl}$ = return duct area in crawlspace, ft^2~~

~~$A_{r,gar}$ = return duct area inside garage, ft^2~~

~~$A_{s,out}$ = surface area of supply duct outside conditioned space, ft^2~~

~~$A_{s,attic}$ = supply duct area in attic, ft^2~~

~~$A_{s,base}$ = supply duct area in basement, ft^2~~

~~$A_{s,crawl}$ = supply duct area in crawlspace, ft^2~~

~~$A_{s,gar}$ = supply duct area inside garage, ft^2~~

~~$A_{s,in}$ = supply duct area inside conditioned space, ft^2~~

~~B_r = conduction fraction for return~~

~~B_s = conduction fraction for supply~~

~~DE = delivery effectiveness~~

~~DE_{design} = design delivery effectiveness~~

~~$DE_{seasonal}$ = seasonal delivery effectiveness~~

~~E_{equip} = rate of energy exchanged between equipment and delivery system, Btu/hour~~

~~$F_{cycloss}$ = cyclic loss factor~~

~~F_{equip} = load factor for equipment~~

~~F_{flow} = load factor for fan flow effect on equipment efficiency~~

~~F_{leak} = fraction of system fan flow that leaks out of supply or return ducts~~

~~F_{load} = load factor for delivery system~~

~~F_{recov} = thermal loss recovery factor~~

~~F_{regain} = thermal regain factor~~

~~K_r = return duct surface area coefficient~~

~~K_s = supply duct surface area coefficient~~

~~N_{story} = number of stories of the building~~

~~P_{sp} = pressure difference between supply plenum and conditioned space [Pa]~~

~~P_{test} = test pressure for duct leakage [Pa]~~

~~Q_a = Flow through air handler fan at operating conditions, cfm~~

~~$Q_{total,25}$ = total duct leakage at 25 Pascal, cfm~~

~~R_r = thermal resistance of return duct, h ft^2F/Btu~~

~~R_s = thermal resistance of supply duct, h ft^{2}F/Btu~~

~~$T_{amb,r}$ = ambient temperature for return, F~~

~~$T_{amb,s}$ = ambient temperature for supply, F~~

~~T_{attic} = attic air temperature, F~~

~~T_{base} = return duct temperature in basement, F~~

~~T_{crawl} = return duct temperature in crawlspace, F~~

~~T_{design} = outdoor air design temperature, F~~

~~T_{ground} = ground temperature, F~~

~~T_{gar} = temperature of garage air, F~~

~~T_{in} = temperature of indoor air, F~~

~~T_{rp} = return plenum air temperature, F~~

~~$T_{seasonal}$ = outdoor air seasonal temperature, F~~

~~T_{sp} = supply plenum air temperature, F~~

~~ΔT_e = temperature rise across heat exchanger, F~~

~~ΔT_r = temperature difference between indoors and the ambient for the return, F~~

~~ΔT_s = temperature difference between indoors and the ambient for the supply, F~~

~~$\eta_{dist,seasonal}$ = seasonal distribution system efficiency~~

~~*RF4.0 Air Distribution Diagnostic Measurement and Default Assumptions*~~

~~4.5.3 Recovery Factor (F_{recov})~~

~~The recovery factor, F_{recov}, is calculated based on the thermal regain factor, F_{regain}, and the duct losses without return leakage.~~

~~$$F_{recov} = 1 + F_{regain}\left(\frac{1 - a_s B_s + a_s B_s (1 - B_r)\frac{\Delta T_r}{\Delta T_e} + a_s (1 - B_s)\frac{\Delta T_s}{\Delta T_e}}{DE_{seasonal}}\right)$$~~ ~~Equation RF14~~

~~4.5.4 Seasonal Distribution System Efficiency~~

~~The seasonal distribution system efficiency shall be calculated using the seasonal delivery effectiveness from Section 4.4.2, the equipment efficiency factor from Section 4.5.1 and the thermal recovery factor from Section 4.5.3. Note that $DE_{seasonal}$, F_{equip}, F_{recov} must be calculated separately for cooling and heating conditions. Distribution system efficiency shall be determined using the following equation:~~

~~$$? _{dist,seasonal} = 0.98\, DE_{seasonal} \times F_{recov}$$~~ ~~Equation RF15~~

~~where 0.98 accounts for the energy losses from heating and cooling the duct thermal mass.~~

~~APPENDIX C~~

~~Pages C-4 through C-60 have been deleted but are reserved for future use for final versions of the sample CALRES input descriptions of the C prototype building and the Custom Budget tests.~~

~~These sample files will be added for information purposes only, and will not be adopted as regulations.~~

~~Pages C-1 to C-3 are available upon request by calling Debbie Friese at (916) 654-4067.~~